EXECUTIVE SUMMARY

To ensure the safety of the construction workers and personnel in bridge construction areas, the proper design and detailing of bridge overhang falsework is essential. In the design of the overhang falsework systems, a problem has been identified by NCDOT design engineers. The problem is in the determination of the ultimate strength and safe working load capacity of falsework hangers on modified bulb tee (MBT) prestressed concrete girders. The hanger manufactures require 5 inches of concrete to embed the hanger and develop the strength into the flange. The MBT girders have a top flange thickness of 3 ½ inches. This results in reduced safe working loads or the use of bearing plates to distribute the forces over a larger area of the flange. The analysis procedures used by the manufactures and NCDOT to predict the strength of the hangers on MBT girders are not consistent and may have resulted in conservative and more costly falsework designs. The focus of this proposed research is to determine the ultimate strength and safe working load capacity of falsework hangers on MBT girders through full scale testing. In addition, an analytical investigation will be performed to develop analysis and design guidelines and detailing recommendations. The results of this study can be directly integrated in the NCDOT design standards for use by contractors and in-house personnel. This will result in more cost-effective falsework system designs.

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RESEARCH PLAN

Introduction

This proposal was developed in response to *Research Idea ST-04* in the NCDOT FY-2005 *Call for New Research Idea*. The research idea was proposed by Mr. Tom Koch, Project Engineer in the Structure Design Unit. The research team submitted a pre-proposal for this project and the Structures Research Subcommittee recommended the development of this full proposal, as stated in the November 24, 2003 letter of the State Research Engineer, Mr. Rodger Rochelle. The Structures Research Subcommittee requested that the scope of work be reduced to include testing of only one falsework detail with an option to test an additional detail. We have incorporated these requests in this proposal.

The proper design and selection of bridge deck overhang falsework systems is an essential part of a bridge construction project. The primary concern is the safety of the construction workers and other personnel in the construction area. A falsework failure can result in loss of life, long construction delays, extensive property damage, and considerable liability expenses. In an effort to avoid these potentially serious problems with the overhang falsework, the NCDOT provides an extensive review of the detailed drawings and calculations submitted for each bridge project. In the course of these reviews, a problem with the use of embedded falsework hangers with modified bulb tee (MBT) prestressed concrete girders has been identified. The problem is that the ultimate strength and safe working load capacity of the falsework hangers embedded in the flange of MBT girders is not known with complete confidence. As a result, overly conservative and costly designs may have been implemented in many cases.

Overhang falsework systems consist of three primary components; the overhang formwork and screed support, overhang support brackets, and diagonal support hanger. There are two overhang formwork configurations commonly used. One configuration uses an embedded bearing type diagonal hanger that is embedded in the edge of the precast girder flange, as shown in Figure 1. Another configuration uses a bolt-through hanger, as shown in Figure 2. The standard edge of flange bearing detail is the focus of the proposed research.

Problem Definition

The design of falsework hangers requires careful consideration of the limit states associated with the falsework hanger, MBT girder flange, and the interface between the two components. Hanger strengths have been established by the manufacturers and are summarized in their product catalogs. The provided strengths consider the unit strength of the hanger, the development of the embedded hanger into the girder flange, and the bearing strength of the hanger on the girder flange. Standard hanger configurations require a minimum flange thickness of five inches for embedment and bearing strength. On modified bulb tee girders, the top flange normally has a minimum thickness of 3½ inches. Since the flange thickness is less than the required five inches, the hanger struts are commonly modified by the manufacturer to provide adequate embedment length. This resolves the problems with the embedment length, but the required bearing strength results in a reduction in the safe working load of the hanger. Recent designs have resulted in a fifty percent reduction of the safe working load for falsework hangers. A common solution to the bearing problem is to provide a bearing plate to distribute the hanger load over a larger area. In either case, the final design is significantly more labor intensive and costly.

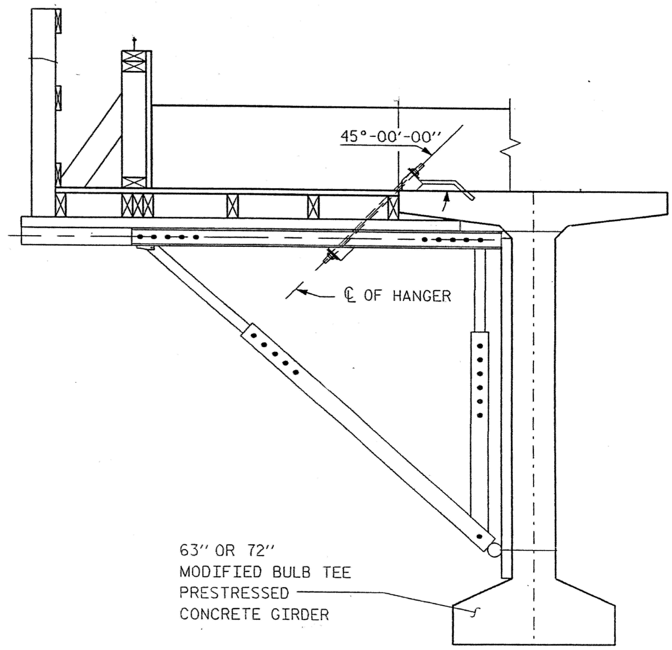

Figure 1. Edge of flange bearing falsework hanger configuration

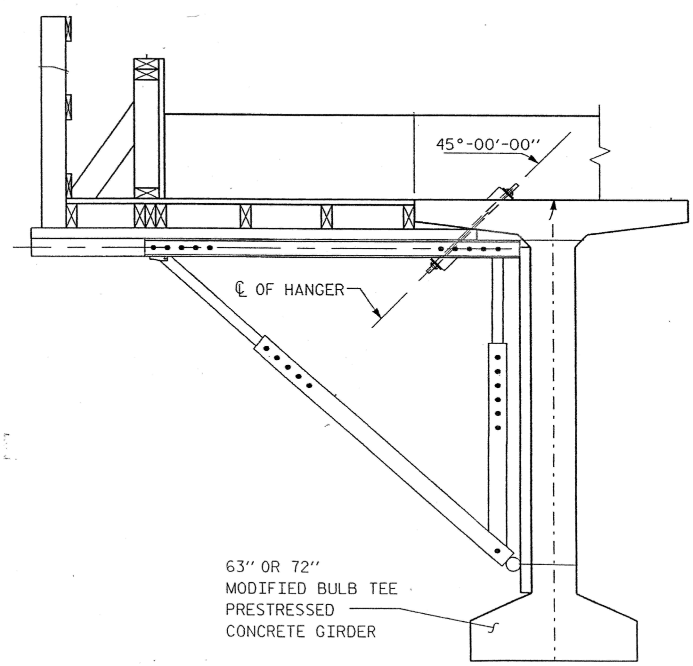

Figure 2. Bolt-through flange falsework hanger configuration

The analysis procedures utilized by the manufactures and NCDOT to determine the bearing strength of the hangers on the girder flanges are approximate and have often led to conservative and costly designs. To determine the ultimate strength of the falsework hangers used with MBT girders, an experimental and analytical investigation is needed. This investigation is the focus of the proposed research.

Research Objective

The primary objectives of the proposed research are to determine the ultimate strength and safe working load capacity of falsework hangers embedded in MBT girder flanges and to make recommendations for the design and detailing of the girder flange to maximize the strength of the system. These objectives will be accomplished through full scale experimental testing and analytical investigation.

Literature Review

There are numerous publications related to the design of formwork for construction of concrete slabs. However, there is very limited published information on the design of overhang falsework systems on MBT girders. As a result, the publications directly related to this research are limited to general design specifications and formwork design manuals. The most relevant publications that will be utilized are as follows: *Standard Specifications for Highway Bridges, Seventeenth Edition* (AASHTO, 2002), *347R-01: Guide to Formwork for Concrete* (ACI, 2001), and *ACI SP-4, Formwork for Concrete, 6th Edition* (Hurd, 1995).

Overall Work Plan

The proposed research is divided into four primary tasks. Details of each task are as follows.

Task 1. Literature review

A comprehensive literature review will be conducted to identify the existing literature relevant to the design of falsework hangers embedded in MBT girder flanges. The review will include published reports from federal and state agencies, archival journals, conference proceedings, masters' theses and, doctoral dissertations. The primary focus will be on the strength of the thin concrete girder flanges subject to concentrated vertical and diagonal loads at the edge.

Task 2. Experimental testing

The experimental testing program will focus on identifying the ultimate strength of the critical limit states associated with the falsework hanger system. The effects of hanger spacing and location along the length of the girder will be investigated. Full-scale testing of falsework hangers embedded in MBT girders will be performed.

Task 3. Analytical investigation

The analytical investigation will focus on the development of guidelines to predict the strength of falsework hanger systems. Analytical modeling and limited finite element modeling will be utilized as appropriate. The analytical and experimental results will be compared and the results will be used to develop design guidelines.

Task 4. Technology transfer

The technology transfer will focus on the dissemination of the research results and design guidelines to the customers at NCDOT.

Experimental Program

Full scale testing of the conventional falsework hanger detail shown in Figure 1 will be preformed. The tested falsework hanger system will utilize Dayton/Richmond C-24 Type 4-APR edge of flange bearing hangers (see Figure 2) embedded in the flanges of a MBT girder. The test specimen will consist of a single 25’-0” long modified bulb tee girder (MBT) with 11 falsework hangers installed at 2’-0” spacing on both sides of the top flange. The anchors will be at least 2’-6” away from the girder ends. The exact dimensions and reinforcing details of the specimens will be selected in coordination with NCDOT engineers.

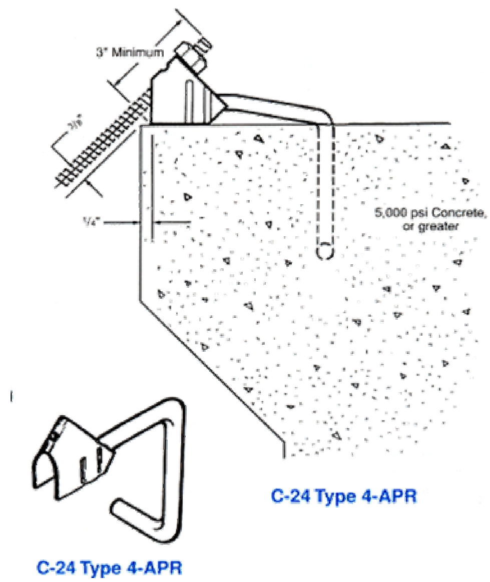

Figure 2: Detail of Dayton/Richmond C-24 Type 4-APR Hanger

The beam will be simply supported and torsionally restrained at the end supports. The hanger rods will be loaded statically to failure using hydraulic jacks. The specimen and the anchors will be instrumented with a variety of potentiometers and PI gages to record the complete responses of the concrete girder and the anchors during the test.

Table 1 shows the test matrix and summarizes the selected test parameters. The constant 2’-0” hanger spacing will allow testing of the hangers at two different increments of 2’-0” and 4’-0”. Two anchors will be loaded simultaneously at the each spacing increment to determine the interaction between adjacent anchors. The 2’-0” hanger spacing will be tested at the girder end as well as the interior locations along the span of the girder. Testing at the two locations will determine if the strength of the hangers are reduced near the ends of the girder.

Another test will be performed to evaluate the MBT girder flange under maximum loading conditions. Hanger spacing of 2’-0” will be utilized and six anchors will be loaded simultaneously. This loading should represent the maximum MBT girder flange loading and will evaluate any global flange failure modes that may exist.

Table 1. Test Matrix (Phase 1)

Test ID	Hanger Spacing	Location Along Span	Number of Anchors Loaded
Test 1	2'-0"	Exterior (end of girder)	2
Test 2	2'-0"	Interior	2
Test 3	4'-0"	Interior	2
Test 4	2'-0"	Interior	6

The specimens will be supported vertically and laterally in a manner consistent with the field conditions. The test setup is shown in Figure 3. Each anchor test will be carried out at a distance away from the disturbed region of the previous anchor test. However, any damage to the girder will be repaired prior to conducting the next anchor test. Details of the repairs will be coordinated with NCDOT engineers.

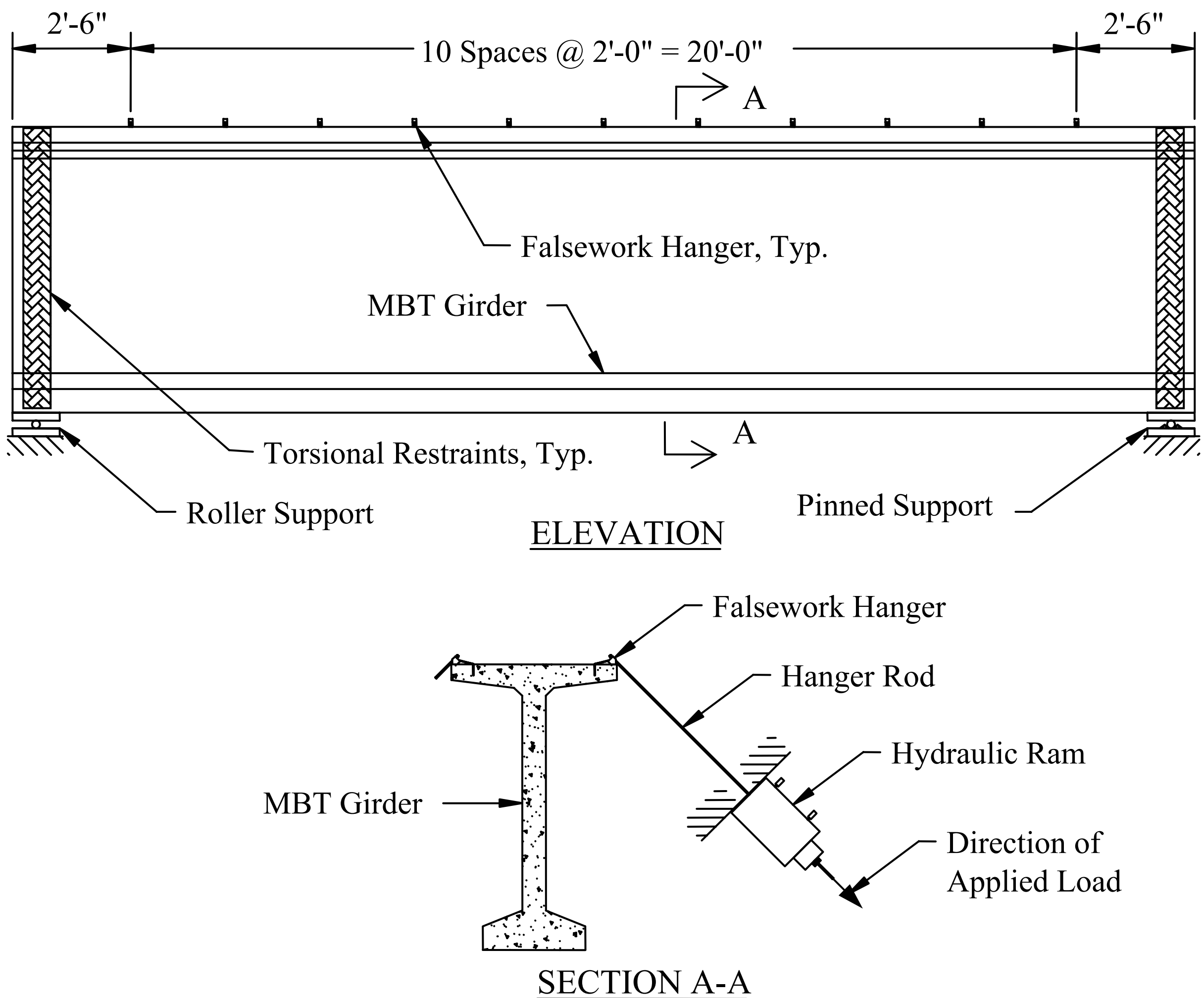

Figure 3: Test Setup - Elevation and Section

Analytical Investigation

An analytical investigation will be conducted to evaluate the limit states associated with the falsework hanger and MBT system. The focus of the analytical work will be to develop design guidelines to predict the strength of the MBT girder flange. In addition, recommendations for strengthening the girder flange will also developed. Analytical modeling and finite element modeling will be utilized as appropriate to predict the ultimate strength and mode of failure. The resulting design guidelines will be included in the final report.

ANTICIPATED RESULTS AND SIGNIFICANCE

The *Structure Design Unit* of the NCDOT has identified the product from this research to be of immediate urgency. We concur with this assessment, and believe that this project can directly and immediately provide benefits in terms of construction cost savings to the NCDOT, both in long-term and short-term. The proposed research will determine the ultimate strength and safe working capacity of the falsework hangers used with modified bulb tee (MBT) prestressed concrete girders. A thorough evaluation of limit states associated with the falsework hanger system will be performed and the results incorporated into the final design and detailing recommendations. These design and detailing recommendations can be integrated directly into the NCDOT design standards for use by contractors and in-house personnel. This will result in more cost-effective falsework system designs.

IMPLEMENTATION AND TECHNOLOGY TRANSFER PLAN

In this section, the main issues regarding implementation and technology transfer of the proposed research are discussed.

What is the primary "Product"?

The primary *products* of this research are the design guidelines for predicting the ultimate strength of falsework hangers on MBT girders.

What are the secondary "Products"?

The secondary *product* of this research is the additional *knowledge* of the behavior of the overhang falsework hanger system and the MBT girder flange.

Who within NCDOT will use the products? (Customers)

The *customers* of the above described products are the NCDOT structure design engineers.

Why should they use the products? (Market)

The structure design engineers can use the resulting guidelines to design more efficient and cost effective overhang falsework hanger systems. Utilization of the design procedures will ultimately reduce the construction costs for MBT girder bridge structures.

How will they use such products?

The design guidelines can be integrated directly into the design process used by structure design engineers. In addition, these guidelines will be directly integrated in the standardized details currently under development by NCDOT engineers.

What is needed for NCDOT customers to use products?

Once the research is complete, appropriate workshops could be used to inform all structure design engineers of the outcome of this research. Once the customers are equipped with the knowledge and guidelines for using the design procedures, they could easily incorporate the procedure into the design process.

The dissemination of the project findings is an integral part of this project. Information will be provided to the NCDOT through quarterly progress reports, as well as a comprehensive final report. The Research Team will work with the NCDOT personnel on developing the most effective means to transfer the knowledge gained in this project to appropriate personnel at the various divisions and districts within the NCDOT.

RESOURCES TO BE SUPPLIED BY NCDOT

The proposed research requires that the NCDOT provide the research team access to the NCDOT personnel familiar with the overhang falsework system analysis and design procedures to facilitate selection of appropriate MBT girder details. No other NCDOT resources will be required.

TESTING FACILITIES

The Constructed Facilities Laboratory (CFL) is part of North Carolina State University's Engineering Graduate Research Center (EGRC). The CFL is a sophisticated structure with specially designed reaction floors and walls to support three-dimensional loading. It houses facilities devoted to the development and testing of innovations to improve the public and private constructed infrastructure such as highways, bridges, industrial plants, buildings, and residences. At the CFL, innovations in construction materials, construction techniques, and analysis and design methods can be developed and tested with prototypes and hands-on experiments as well as computer simulations.

The laboratory allows CFL researchers to develop and evaluate a broad range of conventional and advanced composite materials such as conventional and high-strength concrete; high-performance fiber-reinforced concrete, steel, wood, masonry, and fiber-reinforced polymeric composites as well as large-scale structural systems exposed to static, fatigue, and seismic types of loading. The laboratory is served by two 20-ton overhead cranes. It is fitted with hydraulic pressure lines connected to a 100-gallon/minute capacity hydraulic pump, compressed air lines, outlets to a computer network for data collection, and appropriate electrical service. The reaction floor is a 13-foot-thick cellular box, which is about 120 feet long by 40 feet wide. It is complemented by one fixed and one modular 25-foot-high reaction wall. This configuration allows testing of large structural systems under one or two directional horizontal loading. State-of-the-art apparatuses for testing high-strength materials and large-scale structural systems are also available, including:

1. Nine reconfigurable test frames with up to 2000-kip force capacity and up to a 20-foot vertical clearance.
2. One column-testing frame with a 400-kip force capacity and 25-foot vertical clearance.
3. A closed-loop computer-controlled testing system with a series of two 22-, 55-, 110-, 220- and 440-kip actuators capable of applying both static and dynamic loading, with displacement ranges up to 40 inches for the 440-kip actuators.
4. A 2000-kip Baldwin-MTS closed-loop compression machine.
5. A 220-kip MTS closed-loop universal testing machine
6. A 20-kip Sintech-MTS computer-controlled materials testing machine.

TIME REQUIREMENTS - SCHEDULE OF WORK

The proposed project will require one year to complete. The proposed timeline for the tasks in this project is shown in Table 3 The literature review, and analytical investigation will begin within the first quarter. The experimental testing will begin once the MBT girders are received which would likely be at the end of the first quarter.

Table 3. Proposed Timeline

Task	Year	First				Second			
	Quarter	1	2	3	4	1	2	3	4
Literature Review									
Experimetntal Testing									
Analytical Investigation									
Preparation and review of final report									

QUALIFICATIONS AND ACCOMPLISHMENTS OF RESEARCHERS

The research team consists of two faculty members and one graduate student. Emmett Sumner is currently an assistant professor of structural engineering at the NC State University. He is a professional engineer with industry experience in bridge and transportation structure design. Amir Mirmiran is a structural engineering professor at the NC State University, and also a licensed professional engineer with over 8 years of industry experience. It is anticipated that the graduate student will be a working towards a Master's degree.

OTHER COMMITMENTS OF RESEARCHERS

Next year, Dr. Sumner will be working on the last year of the NCDOT project on prediction of steel girder deflections and he is active in research with the NSF Center for the Repair of Bridges and Buildings with Composites (RB^2C). Next year, Dr. Mirmiran will be working on the last year of an NCDOT project on FRP repair, as well as the NCHRP 12-64. However, he will have ample time to devote to this important project.

DIRECTLY RELATED PUBLICATIONS

AASHTO (2002). *Standard Specifications for Highway Bridges, Seventeenth Edition*, American Association of State Highway and Transportation Officials, Washington, D.C.

ACI (2001). *347-01: Guide to Formwork for Concrete*, American Concrete Institute, Farmington Hills, MI.

Dayton/Richmond Concrete Accessories Product Catalog, Miamisburg, OH.

Hurd, M.K. (1995). *ACI SP-4, Formwork for Concrete, 6th Edition*, American Concrete Institute, Farmington Hills, MI.